IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

Geir HOVLAND et al   Group Art Unit: Unassigned

Application No.: Unassigned   Examiner: Unassigned

Filing Date: November 26, 2003   Confirmation No.: Unassigned

Title: DESIGN OF THICK-WALLED COMPONENTS FOR POWER PLANTS FROM CRACK-GROWTH
MODELS

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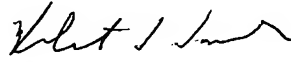Country: Europe

Patent Application No(s).: 02406085.7

Filed: December 10, 2002

In support of this claim, enclosed is a certified copy(ies) of said foreign application(s). Said prior
foreign application(s) is referred to in the oath or declaration. Acknowledgment of receipt of the certified
copy(ies) is requested.

Respectfully submitted,

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Patentanmeldung Nr.   Patent application No.   Demande de brevet n°

02406085.7

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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R C van Dijk

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Anmeldung Nr:
Application no.: 02406085.7
Demande no:

Anmeldetag:
Date of filing: 10.12.02
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Design of thick-walled components for power plants from crack-growth models

In Anspruch genommene Prioriät(en) / Priority(ies) claimed /Priorité(s)
revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

G06F17/50

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of
filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR IE IT LI LU MC NL PT SE SI SK

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Design of thick-walled components for power plants from crack-growth models

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DESCRIPTION

Technical Field

The invention relates to the field of power plant design. It
10 relates in particular to an iterative method and a computer
program product for designing components for industrial plants,
in particular thick-walled components for power plants, as
claimed in the precharacterizing clause of claim 1.

Prior Art

15

Thick-walled components appear frequently in power plants, for
example as tubing for superheaters, reheaters, economizers and
as coolers, drums, rotors, turbine and compressor blades and
casings. Typical component design approaches take conditions
20 such as static water/steam flows, static operating temperatures
and static stresses into account in a steel selection. In one
common design approach, thick-walled components for power
plants are normally designed to last a given number of hours at
a given full load. Full-load equivalent-operating-hours (FLEOH)
25 for each component, e.g. in a boiler, are determined by means

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of look-up tables which are widely available to persons skilled in the art. To find a component's FLEOH, both steady-state full-load temperature and steady-state full-load stress the component is subject to under steady-state full-load conditions
5 are required, as are material properties, e.g. steel type, of the component. When applying this approach, stronger materials will typically be chosen for tubes and welds in superheated parts of a boiler when designing the power plant, thus providing such components with FLEOHs similar to tubes and welds in
10 low temperature regions. The FLEOH number for a component corresponds to a life expectancy of that component when constantly subjected to the steady-state full-load temperature and the steady-state full-load stress. If values for temperature and stress during operation exceed steady-state full-load values
15 assumed when designing the component, the life expectancy of the component will decrease, or, in other words, ageing of the component will be accelerated. As a consequence, the component will fail earlier than expected.

The FLEOH approach is conservative. In general, a power plant
20 will not be operated at full-load at every given moment of its lifetime. An alternative approach is to use load-dependent equivalent-operating-hours (EOH). The EOH is an average estimate of a component's life expectancy based on typical load profiles and typical numbers of start-up and shutdown sequences
25 that occur during a components lifetime. As a result, a more accurate estimate of the life expectancy is achieved and a less conservative design is possible.

In both approaches, however, to ensure that components do not fail unduly, harsher conditions than the ones that the compo-
30 nents will finally be subjected to are assumed when designing said components. This leads to more or less over-dimensioned components, with, in general, thicker walls, larger diameters, materials and welds of higher quality, etc., than would actually be required. This, in turn, leads to higher costs in

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building corresponding plants, namely because of increased material consumption, higher transportation costs due to increased weight of the components, more difficult handling, tc.

5 **Description of the Invention**

It is an objective of the invention presented herein to provide a method and a computer program product of the type mentioned initially that permits a design of components for industrial plants, in particular thick walled components for power plants, 10 that avoids over-dimensioning.

This object is achieved by the method and the computer program product as claimed in the independent claims. In an iteration method for designing a component, in particular a thick-walled component, of a power plant according to claim 1, a dynamic 15 simulation of process variables is used as the basis for a crack-growth simulation. The process variables are computed by means of a process simulator for a given, time-dependent load profile. According to the invention, the load profile is time-dependent and the process simulator is capable of taking into 20 account transient behaviour as it occurs e.g. during start-ups, shutdowns or load changes, so that the computed process variables are also time-dependent. This has the advantage that components can be designed in such a way that their life expectancy under realistic operating conditions accurately matches a 25 desired value.

Further advantageous realizations can be found in the dependent claims.

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Brief Explanation f the Figur s

The invention will be explained in more detail in the following text with reference to exemplary realizations and in conjunction with the figures, in which:

5   Fig. 1 shows a potential location and geometry of a crack in a turbine blade,

Fig. 2 shows a cross section of a pipe, with an example of a crack growth geometry.

The reference signs used in the figures are explained in the
10   list of reference signs.

Detailed description of preferred embodiments

Starting point for the method according to the invention is an initial structure of a component, in particular a thick-walled
15   component, said component forming part of a power plant, which in turn is characterized by an initial structure, wherein the initial structure of the component is comprised in the initial structure of the power plant. The word "structure" in this context refers to a physical, geometrical and material constitu-
20   tion of the component and the power plant, respectively, and comprises shapes, dimensions, steel composition, weld materials, etc. For example, a combined cycle power plant comprises a gas turbine, a heat recovery steam generator, and a steam turbine. The steam turbine comprises a plurality of thick-walled
25   components such as a rotor, a number of pipes, a casing, a number of turbine blades, and a number of vanes. Each component is described by process dynamics, geometrical dimensions and material characteristics. In addition to the gas and steam turbines and the heat exchanger, a power plant may comprise further com-

ponents, e.g. a compressor, a condenser, a feed water tank, a deaerator, coolers and several pumps.

In what follows, the component need not necessarily consist of a single part, but may be a composite component comprising a
5 number of parts that are joined together, e.g. by a weld. In this manner, joints like welds can easily be included in the design process. This is important since many failures encountered in heavy-section piping occur at welded joints. Hence, not only the components base material, but also the weld re-
10 gions require sufficient attention when designing power plants.

In a first step, a response of the steam turbine and/or the gas turbine to a time-dependent load profile is modelled by means of a process simulator. For the steam turbine, for example, elements such as rotor dynamics, steam temperatures, and pres-
15 sure distributions within the steam turbine are taken into account in a simulation. A corresponding modelling methodology is well-known to a person skilled in the art of power plant model-ling, and is, for example, described in detail in the book "Thermische Turbomaschinen" by Walter Traupel, published by
20 Springer, Berlin, 1988, which will be referred to as Traupel in what follows. Implementation of the modelling methodology into a process simulator in turn is straightforward to a person skilled in the art of computer programming. Preferably, rotor dynamics, thermodynamic behaviour of pipes 4, and thermodynamic
25 behaviour of steam within the turbine are taken into account in the simulation. From the process simulation, a plurality of process variables will result, comprising, but not limited to, densities, temperature distributions, pressures and/or veloci-ties of steam and/or fluids. For the gas turbine, pressure,
30 density, velocity of the gas in a high and/or a low-pressure section of the gas turbine, pressure, density, enthalpy may, for example, be obtained by means of the process simulation. Temperatures of steam, water and air in a heat recovery steam generator may also be simulated.

The following mass balance equations are typically used to model the mass flow in a pipe,

$$Vol^{pipei}\frac{d\rho^{pipei}}{dt} = flow_{in}^{pipei} - flow_{out}^{pipei},$$

$$flow_{out}^{pipei} = c^{pipei}\ \rho^{pipei}\ p^{pipei}\ \sqrt{1-(p_{out}/p^{pipei})^{\frac{n+1}{n}}},$$

$$p^{pipel} = z(p^{pipei},T_{in}^{pipei})R\ \rho^{pipel}\ T_{in}^{pipei}.$$

where ρ is the density, p the pressure, and the remaining vari-
5 ables are component specific constants. Similar equations can be written for energy balances and used for turbine and heat exchanger models.

In a second step, stress exerted onto the component will be computed. The following types of stress are taken into account:

10 • Tension stress due to centrifugal forces: pure tension due to the combination of rotor rotation and the blades own weight, for example computed using essentially the follow-
      ing formula: $\sigma_c(r^*) = \frac{\rho_{blade}\ w^2}{area(r^*)}\int_{r^*}^{r_{tip}} area(r)\ r\,dr$, where σ is the ten-
      sion stress, ω a rotational velocity, and ρ a component
15   density.

   • Bending stress due to pressure gradients, for example com-
      puted using a formula taking into account axial and longi-
      tudinal bending moments as described in Traupel.

20

   • Thermal stress due to temperature gradients within the blade, for example computed using essentially the follow-
      ing formula: $\frac{\partial^2\Phi}{\partial r^2}+\frac{1}{r}\frac{\partial\Phi}{\partial r}+\frac{\partial^2\Phi}{\partial z^2}=\frac{1+\nu_R}{1-\nu_R}\beta(T_R-\dot{T}_R)$, where ϕ is the

stress potential, T_R the temperature, T_R^* a mean temperature, and z and r polar coordinates of the component.

- • Dynamic stress due to fast oscillations of process variables caused by flow fluctuations and/or excited eigenfrequencies. This type of stress is especially important during start-ups, shutdowns and load changes. For example pipe stresses are directly proportional to internal pressures that vary dynamically. Similarly as can be seen from the above mentioned stress formulas, thermal and bending stresses are directly related to process variables such as temperature and pressure that also vary dynamically.

Computational procedures for modeling the various stress types are again known to a person skilled in the art of power plant modelling, and are once more described in Traupel.

In a third step, a life expectancy of the component is determined for the given load profile. For this purpose, a hypothetical crack is introduced in the component, and a growth with time of said hypothetical crack is modelled by means of a crack-growth simulator. The hypothetical crack reflects the fact that, even when out-of-the-box new, the component has a number of microscopic or minimal cracks. In addition, it is further assumed that each component has a critical crack length. The life expectancy is the time it takes for the hypothetical crack to reach the critical length. Depending on the type of stress a component is subject to, different models are used to simulate crack growth. For stresses that are approximately constant in time, creep crack growth models are applied.

A typical creep crack growth model is given by $\frac{da}{dt} = \gamma(C_t)^n$, where a is the crack length, C_t a so-called crack tip parameter that depends on the component geometry and applied stress, γ a mate-

rial creep constant, and $m \approx n/(n+1)$ another constant with n being the Norton exponential constant. For stresses that are at least approximately cyclic, fatigue crack growth models are used. A typically used fatigue crack growth model is given by

$$5 \quad \frac{da}{dN} = \frac{C\left(\max(\Delta K - K_{th}, 0)\right)^{nfatigue}}{\frac{K_{crit}}{K_{max}} - 1},$$ where ΔK is the amplitude of the

stress cycle, a the crack length and N the number of cycles and the remaining variables are component specific constants.

The respective models are well-known to a person skilled in the art of mechanical engineering, and are e.g. described in the
10 books "Fracture Mechanics: Fundamentals and Applications", by T. Anderson, CRC Press, 2nd ed., Cleveland, Ohio, 1995; "Advanced Fracture Mechanics" by M. Kanninen and C. Popelar, Oxford University Press, New York, 1985; "Non-linear Fracture Mechanics for Engineers", by A. Saxena, CRC Press, Cleveland,
15 Ohio, 1998; and "Damage Mechanics and Life Assessment of High-Temperature Components" by R. Vishwanathan, ASM International, Ohio, 1989. Implementation of the modelling methodology into a crack-growth simulator is again straightforward to a person skilled in the art of computer programming.

20 To further illustrate how the crack growth simulations may be carried out, Fig. 1 shows a potential location and geometry of a crack 3 that has been growing for some time in a turbine blade 1, said turbine blade 1 being fixed to a rotor 2. When the turbine is in operation, the blade 1 is subject to a ten-
25 sion P and a bending moment M, which are indicated by arrows. Fig. 2 shows a cross section of a pipe 4, with an example of a crack growth geometry for a crack 5 that has been growing for some time in a radial direction of the pipe 4. The pipe 4 is subject to an internal pressure p exerted by flow of gas
30 through the pipe 4.

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The life expectancy of the component obtained from the crack-growth simulation is then compared to a given, desired value. If the life expectancy of the component obtain d from the crack-growth simulation is shorter than the desired value, the

5   structure of the component is modified, and the computation of stress as described in the second step above and the determination of the life expectancy by simulation of crack-growth as described in the third step above, respectively, are repeated with the new, modified structure of the component. This process

10   is continued in an iterative manner until the life expectancy exceeds the desired value.

If the life expectancy is longer than the desired value, the component can be used as is, i.e. the structure of the component does not require further modification. This requirement is

15   already fulfilled after the 0-th iteration if the life expectancy obtained with the initial structure of the component is longer than the desired value. In such cases, the initial structure need not be modified.

In a preferred variation of the method, the structure is param-

20   eterized by means of at least one structural parameter, preferably a plurality of structural parameters. Structural parameters may refer to an inner or outer diameter of a tube, a wall thickness of a casing, a blade/vane height, width, or cord, a rotor mass, structural interconnections, a material composi-

25   tion, in particular a ratio of a certain substance in a composite or an alloy, a material tempering, etc. In the iterative process, the structure of the component is preferably modified by modifying one or more of the structural parameters.

In another preferred variation of the method, instead of com-

30   paring the life expectancy to a given, desired value, it is checked whether the life expectancy falls into a given interval. By applying this variation of the method to a number of components that constitute a subunit of the steam turbine, it

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can be assured that all components in this subunit have the same life expectancy. This is of particular advantage for sub-units that are regularly replaced, as it ensures that no compo-nents with a large remaining life expectancy are replaced un-
5   duly if all components in the subunit are provided with approximately the same life expectancy, i.e. within an interval that is small compared to the life expectancy.

In another preferred variation of the method, not only the com-putation of stress and the determination of the life expectancy
10   are repeated after each modification of the structure of the component in each iteration, but also the process variables are re-computed by means of the process simulator whenever the structure of the component has changed significantly since a previous computation of the process variables. If the structure
15   is parameterized, a significant change can advantageously be defined by specifying for each parameter an allowable relative change, beyond which a corresponding change in the structure has to be regarded as significant.

In another preferred variation of the method, the process vari-
20   ables are re-computed by means of the process simulator in each step of the iteration, i.e. after each modification of the structure of the component.

A computer program product according to the invention comprises a computer readable medium, having thereon computer program
25   code means that, when loaded onto a computer, make said com-puter execute the method or any of the preferred variations as described above in this section.

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List of R ference Signs

1   Turbine blade

2   Turbine rotor

3   Crack in turbine blade

P   Tension

M   Bending moment

4   Pipe

5   Crack in pipe

p   Internal pressure

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PATENT CLAIMS

1. A method for designing a component for an industrial plant,
   in particular a thick-walled component for a power plant, by
   means of an iteration comprising the steps of

   a) computing a plurality of process variables by means of a
      process simulator,

   b) modelling growth of at least one hypothetical crack in the
      component, based on a structure of the component and the
      process variables,

   c) computing a life expectancy for the component by determin-
      ing a time required for a dimension of the hypothetical
      crack to exceed a given critical limit,

   d) modifying the structure of the component,

   e) repeating steps b) through d) until the time required for
      the crack dimension to exceed the given critical limit
      fulfils a pre-determined requirement,

   characterized in that

   - a time dependent load-profile and

   - a dynamic process simulator capable of modelling transient
     process behaviour is used to compute the process vari-
     ables.

2. The method as claimed in claim 1, characterized in that

   - the process variables are re-computed by means of the
     process simulator each time the structure has been modi-
     fied.

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3. The method as claimed in one of the previous claims, characterized in that

   - stress exerted onto the component is computed from some or all of the process variables and

5   - is used as a driving force in modelling the growth of the at least one hypothetical crack.

4. The method as claimed in one of the previous claims, characterized in that

10   - growth with time of a length a of the at least one hypothetical crack is modelled as creep crack growth according to $\frac{da}{dt} = \gamma (C_t)^m$, where C_t a is crack tip parameter that depends on the component geometry and a stress exerted on the component, γ a material creep constant, and m a compo-

15   nent specific constant.

5. The method as claimed in one of the previous claims, characterized in that

   - growth per cycle of a length a of the at least one hypo-
20   thetical crack is modelled as fatigue crack growth model according to $\frac{da}{dN} = \frac{C\left(\max(\Delta K - K_{th}, 0)\right)^{n_{fatigue}}}{\frac{K_{crit}}{K_{max}} - 1}$, where ΔK is an amplitude of a stress cycle, N the number of cycles and the remaining variables are component specific constants.

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6. The method as claimed in one of the previous claims, characterized in that

   - the load profile contains at least one start-up or at least one shut-down of the power plant or .

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7. The method as claimed in one of the previous claims, characterized in that

   - the load profile contains a plurality of load changes.

10   8. The method as claimed in one of the previous claims, characterized in that

   - the structure of the component is modified by modifying its material constitution or by modifying weld materials comprised by the structure.

15

9. The method as claimed in one of the previous claims, characterized in that

   - the computation of the plurality of transient process variables by means of the process simulator comprises a
20   computation of tube temperatures and stress.

10. A computer program product comprising a computer readable medium, having thereon: computer program code means that, when loaded onto a computer, make said computer execute the
25   method according to one of the claims 1 through 8.

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ABSTRACT

In a method and a computer program product for designing a component for an industrial plant, in particular a thick-walled component for a power plant, by means of an iteration, in which
5 the steps of

- computing a plurality of process variables by means of a process simulator;

- modelling growth of at least one hypothetical crack in the component, based on a structure of the component and the
10   process variables;

- computing a life expectancy for the component by determining a time required for a dimension of the hypothetical crack to exceed a given critical limit;

- modifying the structure of the component;

15 are repeated until the time required for the crack dimension to exceed the given critical limit fulfils a pre-determined requirement, a time dependent load-profile and a dynamic process simulator capable of modelling transient process behaviour is used to compute the process variables.
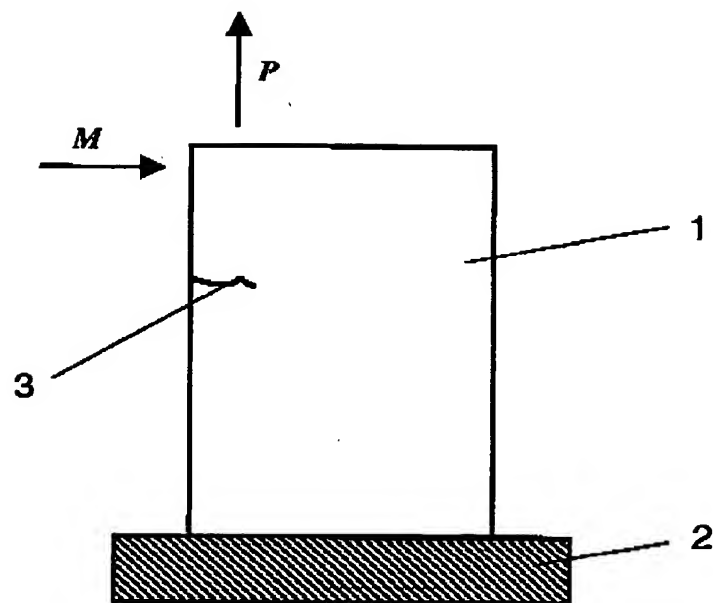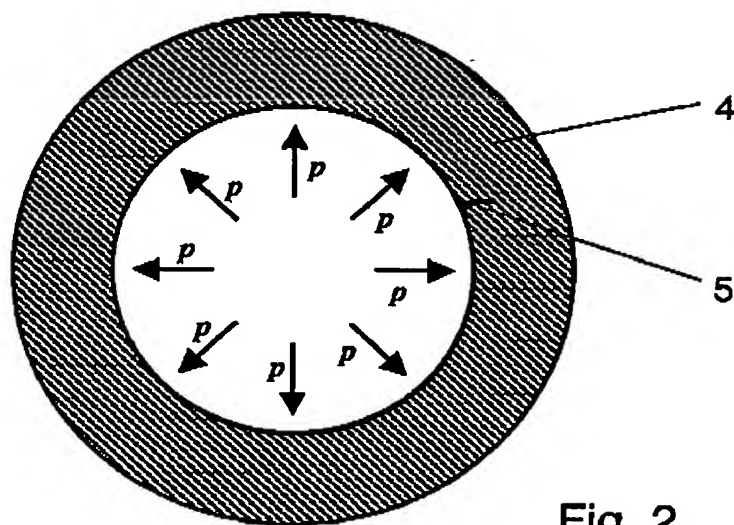
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Fig. 1

Fig. 2